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LHC Communication Infrastructure
Recommendations from the working group

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Abstract

The LHC Working Group for Communication Infrastructure (CIWG) was established in May 1999 with members from the accelerator sector, the LHC physics experiments, the general communication services, the technical services and other LHC working groups. It has spent a year collecting user requirements and at the same time explored and evaluated possible solutions appropriate to the LHC. A number of technical recommendations were agreed, and areas where more work is required were identified. The working group also put forward proposals for organizational changes needed to allow the design project to continue and to prepare for the installation and commissioning phase of the LHC communication infrastructure.

This paper reports on the work done and explains the motivation behind the recommendations.

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Summary

The Large Hadron Collider (LHC) is an accelerator where all measurements and settings will be digitalized at the source and transported in digital form to its destination. In order to manage the transport of the signals for controls, data and supervision, the communication infrastructure must provide transport services capable of supporting the most widely accepted protocols for data, voice and image. The ubiquitous IP/Ethernet is the protocol of choice.

The LHC will operate under the INB convention which will have a major impact on the safety requirements. CERN needs to ensure that the communication infrastructure is sufficiently reliable to ensure delivery of safety information at any time. In addition, the LHC will be under computer control 24 hours a day, 365 days a year for the duration of its lifetime, which implies minimal downtime of supporting technical services. This requires such a high level of communication availability that a single equipment fault cannot be allowed to cause major loss of service.

Such high level of availability is technically possible with a properly designed communication infrastructure and a judicious choice of equipment. However, the operational procedures and the environmental conditions also have an impact, and one must pay attention to these aspects as well.

New solutions for higher level services need to be evaluated in order to take advantage of emerging technologies for transmission of data, video and voice. The goal is to be able to integrate existing and future services in an efficient communication framework which will provide higher availability, better service integration and more efficient operation when the accelerator starts up in year 2005. These new technologies should be evaluated and pilot studies initiated, in order to prepare their introduction at the laboratory.

Important advances in communication technology occur in the industry all the time. The two major market forces are the industry's push toward optical technologies and the ever increasing demand for communication services. Traditional telecommunication gets closer to computer communication, and communications become integrated in informatics services. New technologies emerge and are made available in the market place at a steadily decreasing cost, with higher performance and with enhanced functionality.

At CERN, the communication technologies used for accelerator and detector controls are converging towards industrially available commodity solutions. The LHC will become the next major manifestation of this trend. At the same time, the high speed connectivity made possible by the global optical fiber deployment is creating new opportunities for our users. The overall goal is to make the laboratory more efficient, and to allow the research community to take full advantage of the possibilities offered. In the context of the LHC project, the laboratory has an excellent opportunity to advance the integration of the new technologies into a common communication infrastructure which will tie our users into a community where geographical separation ceases to be a barrier to collaboration. An important recommendation from the working group is to strengthen the communication support group with the related resources in other divisions. The goal is to gather sufficient momentum to be able to meet the challenge of the LHC with an efficient operational unit deploying the most appropriate technology available.

"Perhaps one day, not too far into the future, CERN will be able to offer world-wide interactive controls and processing of physics data, thus creating a research environment on a scale which has not yet been experienced."

1. Introduction

CERN will need a well founded communication infrastructure to support the installation, commissioning and operation of the LHC. This infrastructure must provide communication services support for voice, video and data for the overall laboratory.

In May 1999 a LHC working group was created to collect and review the user requirements and eventually to put forward a proposal for the technical solutions and the organizational structure needed to support the planning, the purchase and the installation of the communication equipment.

Indeed, all groups involved in the construction and exploitation of the LHC will be affected by the communication infrastructure, but in order to allow the working group to proceed efficiently, its size had to be restricted. The members were chosen such that only parties directly involved in the installation and operation of communication services were represented: accelerator controls, the telephone support group, the computer networking support group, the LHC physics experiments and the technical services. Users of the communication facilities were called upon as required during the proceedings.

2. Motivation

The LHC communication infrastructure shall support the following:

- Telecommunication;
- Computer communication;
- Transmission of data for real-time control;
- Transmission of physics data from the detectors.

The technical installations at CERN also include the transmission of many specialized signals which do not fall into any of these categories. Hence the difficulty to accommodate these in the managed framework. The working group has not dealt with the fieldbus installation but we have included the transmission of video, of audio and of accelerator timing. If fieldbus standards evolve to a significant use of Ethernet, responsibility for their support should be reviewed.

Communication has traditionally been done on a system by system basis, by individual, dedicated systems installed by the group directly responsible for the service or even directly by the end-users, thus committing themselves to perpetual operational support. This proliferation of fragmented support responsibilities of similar, but different systems, is not the optimal strategy to manage the resources of the laboratory.

In the communication industry today, there is a noticeable convergence towards common solutions. The new technologies support both the communication needs originating in the telecommunication and in the computer communication areas. The LHC construction time frame will allow us to take advantage of these emerging developments.

There are other constraints posed by the technical installations in the LHC:

- They are partially situated in underground tunnels;
- They are exposed to radiation in some areas;
- They are difficult to access;
- Some of the installations are classified as safety systems.

These constraints call for a high availability infrastructure with on-line, out-of-band, remote performance monitoring and control and a high level of redundancy with automatic switch-over capabilities in case of failure, all supported by an efficient operational organization. In essence, the communication services should be up 24 hours 365 days a year, and downtime periods should be limited to planned interventions for maintenance. It should also be taken into account that the expected lifetime of the LHC is at least 10 years, so the solutions and the investments must have a acceptable perennial value.

3. Time Scale

Installation and commissioning of the communication infrastructure can be assimilated with the General Services as far as the LHC installation schedule is concerned. This allows us to track the schedule requirements from the LHC planning. Civil engineering is already underway, and in October 2000 the dismantling of LEP starts. At that time the existing communication infrastructure in the LEP tunnel will be removed progressively, and all the LHC sites, both on the surface and underground, will communicate through the surface links only. For this intermediate period, the necessary allocation of the resources is already planned, and it will be implemented in the last quarter of the year 2000.

The current LHC installation schedule stipulates that the installation of the General Services in the tunnel starts with Sector 45 at the end of 2001. Working backwards from this date, allowing about 12 months for the purchasing procedure, leaves us until the end of year 2000 to decide the technical specifications of the communication equipment to be installed in the tunnel. This allows us just a few months to get organized after the CIWG proposal is submitted and approved.

The installation of the remaining sectors will follow with some overlap. The plan allows roughly 3½ months for each sector, and the whole tunnel installation will be completed towards the end of 2003. The working group is aware that the order of the sector installations may be subject to modification, but this should not have a major impact on the installation of the communication infrastructure, provided that the duration, the start and the completion dates are maintained.

The working group has also looked into the communication needs for transport of the data from the LHC physics experiments. The schedule stipulates that the commissioning of the LHC shall start in the middle of 2005, which is five years into the future. It is too early to make a final choice of communication technology for this purpose now. Based on the known requirements, however, the working group has not resisted making some predictions into the future of the rapidly evolving communication technology.

The new surface buildings are currently being equipped with communication infrastructure using the present technology. When access to the new infrastructure is available they will gradually be upgraded. During this period, the service will be maintained.

4. Working Method

The working group managed to convene 14 meetings in 1999 and 2000. Information from users was collected by several methods:

- Direct user presentations;
- Fact finding missions by the CIWG members;
- Presentations from other LHC working groups.

The start up of LHC is five years into the future. This means that neither the equipment groups nor other LHC working groups are well prepared to submit specific and detailed needs for communication support at this time. The approach we have taken for each technical area has been influenced by this situation. Another criterion has been the perceived magnitude of the communication needs of each system. The experience from LEP and SPS has helped in these considerations.

Notably, the question about the impact of the radiation level in the LHC tunnel is not yet entirely understood. The preliminary radiation tests which were done in the SPS in 1999 and 2000, have revealed that there is a risk that the tunnel radiation may damage electronics. Several of the LHC equipment groups are now reconsidering their tunnel installation, and they may very well conclude that the controls equipment with electronic components should be retracted to a safer area. This will impact the type and quantity of network attachments required in the alcoves and the underground service areas at the intersection points.

In December 1999 the preliminary findings of the working group were exposed to a wider audience during the Controls and Operation Forum. During the Spring 2000, the broad conclusions of the working group were presented to the LHC management.

5. Hearings Held

The working group first concentrated on technical systems which will be needed early in the construction phase: the personnel access systems, telephone service, the cooling and ventilation services and the monitoring of the technical services. Then we moved on to systems which will be omnipresent in the underground areas and/or in the surface buildings. These included the beam instrumentation systems, the cryogenic system and the vacuum system. We also heard from the more specialized systems like the LHC radio frequency system, the accelerator timing system and the LHC working group for data interchange. This line of approach was successful in cases where the design was well advanced, but for many groups it was too early in the design phase. Reasonably accurate predictions for many other systems can probably be made by counting the number of equipments to be installed and extrapolating, based on the experience from LEP and SPS.

One disruptive factor in this approach is that a large fraction of the equipment in LHC will be controlled by programmable logic controllers (PLC). The PLCs will be tied together by the fieldbus, and they will communicate with the communication infrastructure through a *master* PLC. These systems are designed to work autonomously, at least in a fallback mode of operation. The fieldbus itself is not considered to be within this working group's mandate, but the communication infrastructure will allow communication between PLCs, using IP/Ethernet connections. This is the solution which has been chosen for the cryogenic system.

It also appears that the bandwidth requirements for many of the technical systems we deal with in the accelerator are relatively low with respect to today's high performance network devices. Possible disruptive factors could be the creation of video signals at the level of the equipment itself and control applications which involve large numbers of complex devices situated all around the accelerator.

The working group also heard a presentation from the representatives of the four LHC experiments which summarized their communication needs for both detector control and the transport of the physics data from the sites of the four experiments to the computer center.

A fact finding mission met with the fire brigade to collect their requirement for wireless radio during emergency interventions underground.

6. Conclusions

The LHC accelerator will occupy the same tunnel as LEP. In addition, new transfer tunnels will be constructed from the SPS. The underground areas will need a completely new installation of communication infrastructure. On the surface, the LHC will inherit some of the LEP communication infrastructure. In this context, the cable trenches across the countryside are of some concern. These trenches converge towards building 874, which by default has become the site of the central communication node for the accelerator. We refer to this building as the *communication center* in this report. Another point of convergence is the *computer center* in building 513. These two locations represent common points of failure as far as network topology is concerned.

Both the LHC and the SPS will be subject to approval according to the *Installation Nucléaire de Base* (INB) convention between CERN and the French authorities. CERN needs to convince the INB inspectors that the technical installations are sound, that safety is taken care of and that operation follows approved procedures. The communication infrastructure is an essential component for safe operation of the machine and will also need the INB approval.

In order to stimulate the discussion in the working group, a few possible technical solutions were put forward. Some of these, like 10 Gigabit Ethernet, will probably become available during the LHC construction period, whilst others, like optical networking, appears to be premature or too expensive to be widely deployed at this time.

Below we discuss a little more in detail the various needs and requests in addition to some operational requirements for LHC:

6.1. Video Transmission

The site surveillance and personnel access systems need a video and audio capability for transmission of camera video. Several equipment groups also asked for video transmission from the equipment level to the control rooms. Considering that potential video sources may consist of several hundred individual instruments, the implications of these requests could become overwhelming.

In order to make best use of the available bandwidth, some measure of management and control must be deployed to control the video sources, the compression technique and the routing of the video streams.

The choice of the most appropriate solution is not evident because of the rapidly evolving technologies and the high commercial stakes in this field. Today, we see a proliferation of different proprietary systems in use here at CERN, and a convergence is desirable in order to simplify the support situation. At this time, it may still be useful to distinguish between the commodity TV display, video and audio for access and site surveillance and the more sophisticated visualization of dynamic images in the informatics environments, mostly useful in the control rooms. The working group believes that this topic merits a more in-depth study, and recommend that an evaluation project is launched with participation from the users of such systems.

6.2. IP/Ethernet for Controls

At present, the Ethernet backbone at CERN is being upgraded to Gigabit Ethernet. Like everywhere else at CERN, the IP/Ethernet connections are assumed ubiquitous in the LHC surface buildings, in the underground service areas of intersection points and in the alcoves. In the controls context, these connections will be used to connect the equipment controllers or the *master* PLC as the case may be for each type of equipment. In addition, some site wide systems, like the controls for the cryogenic systems, has chosen to exploit the IP/Ethernet to interconnect all their PLCs.

The four LHC experiments: ALICE, ATLAS, CMS and LHCb, all asked for 1 Gbit/s Ethernet each for detector controls. This number includes their need for audio and video channels. One Gigabit Ethernet backbone supplied to each of the experiments will satisfy these requirements. The experimenters want their controls network to be part of the general CERN network, therefore their four backbones will integrate into that network at a high capacity node, perhaps best situated in the computer center.

None of the accelerator controls groups have identified requirements which would exceed the 1 Gbit/s transmission capacity in a single LHC sector. We therefore assume that a Gigabit Ethernet backbone segment for the intersection point and for the two sector alcoves will suffice for access to the accelerator equipment. This infrastructure will also be able to support a limited number of video channels. Most of this capacity will be directed to the control and communication center in building 874 where the surface trenches meet. Another site to be included in this network is SM18 where there is a substantial concentration of accelerator equipment.

A separate, but equivalent infrastructure is needed for the supervision and controls of the technical services. This infrastructure could also serve as one of the redundant channels for the transmission of safety information. The recommendations for the transmission of safety alarm information calls for two dedicated transmission systems. The working group, however, believes that at least one transmission channel can be provided by the technical services network which will be made available in all the necessary locations. The technical control room (TCR) and the safety control room (SCR) should be included in the layout of this network.

All these needs are similar, and they can be satisfied using established technology. This will help to make the infrastructure homogenous and allow for efficient deployment and operation.

It is to be expected that database services situated in the computer center will be used extensively to archive trend data and other measurements originating in the accelerator control system. Hence the need to provide sufficient communication capacity between the communication and the computer centers.

6.3. Transmission of Physics Data

The four LHC experiments: ATLAS, CMS, ALICE and LHCb have also presented their needs for transmission capacity for the transport of physics data between the counting rooms and the computer center.

The LHCb experiment has asked for a transmission capacity of 1 Gbit/s for the transport of physics data from the experiment. This demand can be satisfied by available technology.

ATLAS and CMS have asked for 5 Gbit/s. It is not too optimistic to anticipate that their needs can be satisfied by attaching each experiment directly to a reserved backbone of the emerging 10 Gbit/s Ethernet.

ALICE has asked for 60 Gbit/s. Here another solution has to be found if we are to avoid deployment of parallel network attachments and channels.

The requests from the experiments are not final. The demands are based on a scenario where there is local event filtering at each experimental site. In case this assumption is invalidated, and that data processing and/or storage equipment is installed elsewhere (for example in the computer center), then the needs for transmission of physics data across the sites could increase significantly. Therefore we need to ensure that sufficient flexibility is built into the communication infrastructure from the start, such that more transmission capacity can be made available, should the need arise.

6.4. IP External Access

Users of the control systems assume that they will be able to access the system by means of home or portable computers at any time from any place, either through the Internet or the public telephone network. This facility helps keep the accelerators and experiments running 24 hours a day with a bare minimum of human resources. The automatic callback system (ACB) has become indispensable for this service. This system also protects against unauthorized access to the CERN network. The ACB service or an equivalent should be maintained and improved with higher access speeds (56 kbit/s, ISDN and beyond) and more flexible functionality. The evolution of the service is currently subject to discussion in the CERN Desktop Forum.

The existing system is based on the assumption that access is via a modem connected to a personal computer. We recommend that work is carried out to evaluate the feasibility of using an advanced portable device with graphics capabilities for this service.

6.5. IP Access Protection

The equipment of the physics experiments is mostly connected to the CERN general network. Access protection is provided by the external gateways which reject unwanted traffic coming from the Internet. The control systems for the accelerators have an additional layer of protection because the controls networks do not route to the Internet. Neither method gives total protection against unauthorized access. In order to enforce a more tight access control, a security perimeter must be drawn around the computer system as well and perhaps even around the applications. Such enhanced access security measures require resources and knowledge and may reduce flexibility in operation.

6.6. Telephone

All surface buildings must be equipped with telephones according to the CERN telephone deployment plan. The plan takes into account the designation of the building and the safety requirements for the area. In the context of this report it is useful to distinguish between different types of telephone installations:

- The fixed telephones available in public areas;
- The fixed telephones installed in the offices;
- The mobile telephones;
- The fixed "red" telephones installed for usage in emergency situations.

The "red" emergency telephones will not be installed generally around the LHC. They will at most be restricted to areas which present particular dangers. The telephone signal from these phones will be routed to the PABX, as for normal phones, but the signal from the relay switches of the handsets will be grouped together in such a way that the signature of resulting alarm signal directs the intervention of the rescue team.

It is possible that the deployment plan for fixed telephones should be modified for the LHC. It may be useful to launch a wider discussion on the role of the fixed telephone installations in the laboratory. The advent of the mobile telephones with the CERN Closed User Group is one new factor to take into account. IP telephony is certainly another emerging technology to consider in this context. A decision on the deployment of IP telephony can be expected in 2001.

All users responsible for underground installations have expressed the need for wireless telephone service everywhere accelerator equipment is installed. This will require antenna (leaky feeder) and relay installations in all underground areas.

6.7. Intercom

A general intercom installation in all the LHC underground areas has not been requested. The SL/LRF group has asked for an intercom installation in the electrically noisy klystron galleries around LHC intersection point 4 with connections to the control rooms. If a GSM based solution proves impractical, an alternative would be an IP based intercom system.

6.8. Radio Communication

In case the fire brigade has to intervene in a smoke filled underground area, the advance of the harnessed vanguard equipped with breathing apparatus is coordinated from the intervention control center. This center will normally be situated in the air-lock at the bottom of the lift shaft. Liaison is maintained by means of the fire brigade's two-way radio. Because of the frequency used, this radio works best under line-of-sight conditions. Hence the need for radio relay interconnects and antennas in the tunnel. This infrastructure needs to be restored in the LHC tunnel and also to be extended to cover the new transfer tunnels.

6.9. Closed-loop Real-time Beam Control

Work done in the Dynamic Effects Working Group (DEWG) has revealed that provisions need to be made for real-time control of the two LHC beams. For the communication system, this implies that the readings of the 512 * 2 Beam Position Monitors (BPM) must be transmitted to the control computer, and that the correction settings must be transmitted back to the power converters in real-time. The transmission delay must be short enough to ensure a sufficient phase margin of the control loop, and there must be little jitter. The intrinsic bandwidth of the power converters and magnet system is in the order of 1 Hz. It is accepted that the reading rate of the BPM should be 10 Hz in order to satisfy the stability criterium of the sampled control loop with a margin. The traffic created by this system will be in the order of megabits per second. There will be about 12 signal sources (network connections) in each of the alcoves and the intersection points. It is possible that readings of other detectors also need to be entered into the correction algorithms, which may further increase the traffic.

We can consider three alternative solutions for the transmission the measurement data and the corrector settings in the LHC:

- Point to point links;
- Asynchronous Transfer Mode (ATM) ;
- IP/Ethernet.

A pilot project using ATM is underway in the SPS. Point to point links would need to be multiplexed in order to reduce the cabling. Both these methods would no doubt satisfy the requirements with regard to transmission delays and jitter. A global ATM infrastructure covering the whole LHC would be expensive, and it would introduce a technology not used elsewhere at the laboratory, thus creating another support and operational problem. The IP/Ethernet option would allow us to use the ubiquitous IP/Ethernet infrastructure for the real-time as well. However, in order to convince ourselves, we need to do further studies to investigate the transmission and jitter characteristics for IP/Ethernet configured for predictable transport.

6.10. Transmission of Safety Information

The transmission of safety information requires particular attention because down time cannot be tolerated. It is imperative to avoid that a single fault causes complete loss of alarm information. Two independent and dedicated systems have been proposed for the transmission of alarm information. The working group believes that at least one of the systems could be a channel in the technical services network. We believe that this class of information also can be transmitted on the IP/Ethernet transport provided precautions are made to protect the installation and the operation of the network. Hence the need for redundancy of equipment, protection of the signal paths and protection against power failures (see below).

6.11. Protection and Redundancy for each Sector

The LHC communication infrastructure will be used for a variety of higher level services. The availability of these services is of great importance for the successful operation of the machine, for protection of the accelerator components and of the personnel. Hence the need to incorporate sufficient redundancy into the system such that the detection of a component failure will automatically initiate failure recovery.

Protection against a single cable fault can be achieved by breaking the network up into interconnected ring structures. One possible configuration is to feed each LHC sector with counter rotating bidirectional communication rings. The sector rings interconnect in the communication center. The cable path for each sector lies in a surface trench between the communication center and a LHC shaft. The path then feeds through the tunnel and visits the two alcoves before it emerges at another shaft and is passed back to the center through a separate surface trench. It is important to select the surface paths such that the forward and the return paths do not share the same trench.

When the continuity of the bi-directional ring is broken, either because the cable is cut or a node fails, the ring offers an alternative path to the downstream nodes in the opposite direction. The intermediate communication nodes will have a self-healing capability built in, such that they detect the anomaly and select the alternative path. The switch-over period must be so small that loss of data is avoided.

The sector rings will give us another advantage during the construction period. As each sector is made ready for installation of the machine components, its sector ring can be installed and made operational, while the construction work continues in the other sectors.

6.12. Network Redundancy

The ring protection should be complemented with redundant hardware in the network devices. This is of particular importance in the underground areas which are inaccessible during accelerator operation. Many manufactures provide redundancy built into their equipment to improve the reliability. An alternative is to duplicate the network devices and their network attachments. The communication devices must have an active surveillance mechanism which switches automatically to the redundant hardware in case of failure. Alarm information from the network devices must be made available in the Technical Control Room (TCR).

6.13. Electric Power

Other likely failures can be attributed to environmental conditions. Experience at CERN shows that the electrical power is an important reliability factor. In view of the requirement for high availability of the communication system, the networking devices should be equipped with dual power supplies connected to two independent and reliable power sources. If only a single source is available, it needs to be backed up with a battery source to feed the second power supply.

6.14. Radiation

A basic assumption is that fiber optic cabling will be used to interconnect the nodes in the backbone of the communication system for LHC. With data rates in the Gbit/s range over the distances involved, no other transport media can offer the required capacity. Fiber optic material is adversely affected by radiation, and we need to protect the installation as much as possible from its effects.

In order to reach the alcoves, the cable path has to pass along the tunnel where it will be subject to radiation. Over time, this will render the optical fibers inside the cables opaque. Theoretical calculations, supported by field tests, indicate that the lifetime of a fiber is in the order of years. We assume that the deterioration process will occur gradually over time. In order to track the degradation and build up a trend database, we need to have remote access to on-line measurements of the transmission characteristics of the fibers and to the power levels of the lasers and the detectors.

Should it become necessary to replace a length of optical cable in the LHC tunnel some time in the future, installation time could be reduced if an additional pulling tube were already available. This tube could be mounted in an accessible area of the tunnel cross section already at the time of the LHC construction. Such a simple precaution would allow the cable to be replaced efficiently, causing minimal perturbation for operation of the machine. Only when the replacement cable is operational, would the original be removed.

6.15. Allocation of other Optical Fiber

Some applications: Accelerator Timing, Radio Frequency, Industrial Proprietary Systems, demand allocation of "dark" optical fibers to support their particular transmission needs. The initial request may appear well founded, but the deployment raises a question of long term maintenance. Fault diagnostics become labor intensive with at least two teams involved simultaneously working with access in the remote sites. The repair is complicated as it requires physical reallocation of fibers in the best of circumstances, or very time consuming if whole cables have to be replaced or spliced. The interruption of service may not be acceptable for many on-line services, some also being safety related.

We will discourage allocation of dedicated fibers and rather ask users to consider the recommended IP/Ethernet alternative. On this service we will provide redundancy and protection as described above.

6.16. Timing Distribution

The accelerator timing distribution is one of the few areas where dedicated allocation of "dark" fibers is warranted. Several of the LHC timing signals (the revolution frequency and the bunch train) will be encoded onto a single fiber for the long haul and decoded for local distribution near the destination. This distribution will use custom built laser transmitters and detectors, designed to insert the optical signal directly into the optical fiber.

The radio frequency group has also asked for a set of un-managed optical fibers for synchronization purposes. Some of their fibers, however, are of a particular temperature compensated construction. We include them here because they share the cabling and termination facilities with the rest of the fiber cable installation.

6.17. System Maintenance

An important cause of perturbation is the human factor. Operator errors may occur during system maintenance and operation. The intention behind the intervention is always the best: to help the users. However, because of poorly defined managerial procedures, the task may produce unexpected side effects. CERN is probably more prone to this than industry in general, because we are in a laboratory, and service personnel are expected to respond with flexibility to the requests from our users.

Hence the need to define the managerial process leading up to the modifications and the maintenance tasks. The process must define how these tasks are reviewed and executed. In order to be successful, the process must be accepted and respected by all parties involved. Training is probably the key to find a common ground of understanding of this requirement.

6.18. Availability of Optical Fiber

The surface fiber cables to LHC intersection points 5, 6 and 7 will be upgraded in 2000. This work is part of the LEP dismantling project. The new cables will initially provide communication services at these points for the duration of the construction period. Subsequently, they will be integrated into the communication infrastructure. The fiber cables are sufficiently dimensioned for the needs as we know them today.

The working group has noted that the number of fibers available is limited in some the surface trenches, notably to intersection points 2, 3 and 4. Already today, there is not enough unused fiber capacity available here to implement the required transport services. Hence, a general upgrade of the fiber cables to these three points is required.

7. Recommendations

7.1. Boundary conditions

In addition to the identification of the broad requirements for communication infrastructure of the LHC, the working group has identified the boundary conditions for its implementation:

- LHC and SPS will operate under the INB convention.
- The equipment of the LHC will be under computer control 24 hours a day, 7 days a week, 365 days a year.
- The existing cable trenches to the remote LHC sites impose a common interconnection point in building 874 which represents a single point of failure.
- The cabling in the LHC tunnel will be subject to radiation detrimental to the transmission capabilities of the optical fiber. The lifetime of the fibers will be limited. Recent tests and analysis indicate a lifetime of the order of years.
- It is a fact of life that new requirements will surface during the installation phase. We need to plan with flexibility in mind.

7.2. Consensus reached

The working group has reached consensus on important issues leading up to solutions for the global design of the communication infrastructure for the LHC. The discussions have been guided by breaking the infrastructure up into five communication arenas:

- The general purpose network at CERN.
- The physics detector controls network.
- The technical services network.
- The LHC accelerator network.
- The transport network for physics data from the experiments.

It should be noted that these conceptual networks are not necessarily separated, hence they may very well coexist on the same wire. The technical services network, however, should be physically separated as far as possible, in order to serve as a second channel for alarm transmission.

The working group concluded that optical fiber is the media of choice for the communication backbone, and that IP/Ethernet is the protocol of choice for network connections with Gigabit Ethernet capacity in the backbone. Whilst the choice of fiber was obvious for the surface link, some doubt persisted for the underground areas. Here the fiber cables will be subject to radiation. The latest estimates of the radiation levels in the tunnel, supplemented by the tests of the fiber cable done in the target area of the SPS, predict that the lifetime of the fiber will be in the order of years, hence the working group concluded that the installation of fiber cable in the LHC tunnel is a practical proposition.

Copper cable is the preferred connection medium between the networking devices of the users and the interconnection units branching off the backbone.

The availability of the communication infrastructure is of paramount importance for the commissioning and the operation of the LHC. For this reason, self-healing and redundant capabilities should be built into the structure of the networks and the equipment itself. The working group recommends that the network segments are laid out in ring configurations such that the implicit alternative transmission path to downstream nodes can be activated automatically in case the ring is broken in a single point.

The operational and managerial processes required for the support of the communication infrastructure should be clearly defined and documented. Appropriate procedures for the approval of network interventions must also be defined, and the processes must be supplemented with specific training programs for the network managers, operators and technicians.

The choice between wavelength multiplexing versus fiber intensive cable installations was regarded as a cost consideration. Today, the situation at CERN is such that fiber intensive cabling turns out to be less expensive. This situation may change in the future. For the time being we regard the installed fiber capacity as a vast bandwidth reserve. Should more bandwidth be needed in the future, we could deploy wavelength division multiplexing on the installed fiber cables as required, with a minimum of perturbation to the existing services. This could be of great value, for example, in case the direction taken by the physics experiments should dictate a new configuration for the event filtering.

Today, we know that three of the LHC experiments will need more than Gigabit Ethernet capacity for transport of physics data from their respective experimental halls to the computer center. ATLAS and CMS require 5 Gigabit/s each and requirements of ALICE are in the order of 60 Gigabit/s. ATLAS and CMS could be equipped with 5 parallel Gigabit/s channels to satisfy their requirements. However, the working group anticipates that higher backbone capacities, like for example 10 Gigabit/s Ethernet, will become available well before LHC start-up in 2005. We also know that systems at even higher rates are operating in the communication laboratories today, so we are confident that even the needs of the ALICE experiment can be satisfied in time, with only a few pairs of optical fiber.

7.3. Outstanding issues

The working group has taken note that the responsibility for communication and networking at CERN is divided between the informatics division (IT), the technical services division (ST) and the accelerator division (SL). This fragmentation of resources leads to duplication of work and an overall inefficiency.

In spite of the large number of technical factors that the working group has addressed, many details still remain to be clarified. The present CIWG is not the most appropriate forum to execute that kind of design work. This is also the case for the technical and budgetary planning of the installation. Such work can be executed more efficiently in a single specialized communication group.

Specific, important services which need to be addressed are:

- The telephone services, standard and emergency, fixed and mobile;

- Transmission of information related to safety;
- Intercom functions;
- Video distribution and control;
- Real-time data transmission and predictable transport;
- Remote and wireless access, beyond the present automatic call back and wireless LAN.

The working group recommends that emerging technologies are studied with our users in order to evaluate whether they are appropriate for deployment at CERN in the LHC time frame.

7.4. Proposal for Organizational Support

For historical reasons there are three major communication support groups at CERN:

- The IT/CS group supports the general IP/Ethernet at CERN. They also support the external connections to the Internet. Their installation is large with many thousand network devices. The backbone is currently being upgraded from FDDI to Gigabit Ethernet. Operation of the network has been outsourced.
- The SL/CO/NM was established to support LEP operation in the late 1980s. There was an early requirement for 24/7 operation which had to be supported locally at the time. The original backbones relied on time division multiplex (TDM) for the transmission of data, but later evolved towards FDDI. Because of the INB requirements, two separate networks were supported: the LEP accelerator controls network and the LEP services network. Over time, the technical control room (TCR) became the major user of the LEP services network, which gradually became the general technical services network and which continues to grow. Today, it covers every corner of the CERN sites. The LEP accelerator controls network, however, will disappear when LEP is dismantled in late 2000. SL/CO/NM is also responsible for the networking in the SPS and the PS accelerators.
- In addition, a small section in SL/CO continues to support the TDM system which was installed for LEP early on. The activities of this small group has expanded over time. Today, they maintain a large portion of the fiber optic cable installation, on the LEP site and elsewhere, mainly to support the technical services and the telephones, but also to satisfy particular user requirements.
- The ST/EL group supports the telephone systems at CERN. This includes then normal telephones, emergency telephones, the portable telephones and the PABX. In addition, the group supports other transmission systems for voice and video.

By regrouping and consolidating the resources, sufficient momentum can be reached to create the synergies required to optimize the support in terms of manpower, equipment and operational cost.

With LEP dismantling, scheduled for 2001, now imminent, the opportune moment has come to review the support situation for communication infrastructure in general. The LEP accelerator controls network in the underground areas will be removed. Hence, the need for support of this network will cease. The technical services network require support for 24/7 operation. IT/CS is committed to 24/7 operation of the general informatics network. The communication infrastructure for the LHC will have similar operational requirements.

Operation of a multitude of CERN-wide networks does not make sense in view of the planned staff reductions. The working group therefore propose that the operation of all the CERN networks are consolidated into a single organizational structure. The operation should be organized as a two level support structure, where the first level is the technical control room (TCR). The second level will be called upon to execute interventions on the installation. It could be outsourced if so desired.

The budgetary responsibility for the installation of the communication infrastructure should be attached to a single organizational entity in order to ensure realistic cost estimates for all components, to provide budget control, project management and coordination.

A logical step is to merge the responsibilities for the technical services network into the IT/CS group. The operational aspects could then be incorporated into the existing service contract in order to achieve 24/7 operation according to a service level agreement. Over time, we would also see a convergence in the choice of technology with a smaller variety of equipment to maintain. The IT/CS would also become responsible for the planning, installation and operation of the controls networks for the LHC accelerator as well as the detectors.

CERN should centralize the raw cable installation in a single unit. The responsibility of the unit should include both copper and optical fiber cables. The unit must possess the necessary expertise to complete the installation with the rack mounted terminations and to pass the acceptance tests. It is proposed that the unit is assigned to the ST division.

A number of smaller working groups should be organized in order to investigate the outstanding issues, and pilot projects should be organized to evaluate the emerging technologies in the context of CERN's needs during the LHC period. The time scale for these projects is rather short, considering that the year 2001 will be almost entirely devoted to the procurement process prior to the installation work planned for 2002, 2003 and 2004.

Considering that the mandate of the Communication Infrastructure Working Group has been largely fulfilled, and that the preparation for the LHC communication infrastructure now enters its next phase, the working group proposes to transform itself into an advisory body which will keep itself informed about the progress of the work and will be prepared to advise on technical and organizational issues which may arise if the future.